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Green Data Centers as Strategic Assets: A Bibliometric Review of Energy Efficiency, ESG, and Competitive Advantage

Rinaldi Noor[1]*, Alfira Sofia[1], Lili Adi Wibowo[1], Desi Arisandi[2]

[1]Faculty of Economics and Business Education, Universitas Pendidikan Indonesia, Bandung, Indonesia, [2]Faculty of Information Technology, Universitas Tarumanegara, Jakarta, Indonesia. *Email: naldi@upi.edu

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ABSTRACT

The rapid expansion of digital infrastructure has positioned data centers as critical components of the digital economy while intensifying concerns over energy consumption and environmental sustainability. In response, a growing body of research has examined green data centers as a means of improving energy efficiency; however, strategic and governance perspectives remain fragmented. This study aims to systematically map the intellectual, conceptual, and thematic development of green data center research, with particular attention to its links with energy efficiency, environmental, social, and governance considerations, and competitive advantage. Using a systematic literature review combined with bibliometric analysis, this study analyzes 1,431 Scopus-indexed journal articles published between 2015 and 2025. The analysis employs descriptive performance indicators, citation and co-citation analysis, co-word analysis, thematic mapping, thematic evolution, and bibliographic coupling using Biblioshiny. The results reveal a sharp increase in publications after 2020, reflecting heightened academic and policy attention to the energy intensity of data centers. The intellectual structure of the field is dominated by highly cited studies on the optimization of computing systems and energy efficiency. At the same time, co-word and thematic analyses identify energy efficiency and green computing as core driving themes. Thematic evolution indicates a consolidation toward data center–focused research, yet strategic management and environmental, social, and governance perspectives remain weakly integrated. Overall, the findings suggest that green data centers are still primarily conceptualized as technical solutions rather than as strategic assets embedded within organizational sustainability strategies.

Keywords: Green Data Centers, Energy Efficiency, ESG, Bibliometric Analysis, Competitive Advantage
JEL Classifications: Q40, Q56, O33

1. INTRODUCTION

The growth of the global digital economy, spurred by cloud computing, has heightened the significance of data centers as essential infrastructure, while also increasing energy consumption. The rise of cloud computing has increased energy demand in data centers, thereby amplifying their carbon footprint and associated environmental impacts (Gupta et al., 2021). Energy consumption by data centers is projected to increase from 200 TWh in 2016 to 2967 TWh by 2030, underscoring the urgent need for energy-efficient alternatives (Katal et al., 2022). Numerous methods have been investigated to enhance energy efficiency, including integer linear programming models that can yield up to 38% energy savings compared to conventional approaches (Osman et al., 2021). Furthermore, machine learning and optimization techniques have demonstrated potential savings ranging from 1.6% to 97%, depending on the method employed (Panwar et al., 2022). The implementation of innovative technologies, such as liquid cooling, could further reduce electricity consumption and emissions, with potential reductions of 3.16% in electricity demand and 23.04% in emissions if widely adopted (Coyne and Denny, 2021). Collectively, these findings underscore the urgency of sustainable innovation and supportive policy frameworks to enable a transition toward low-carbon digital infrastructure while maintaining the essential services provided by data centers (Coyne and Denny, 2021; Katal et al., 2022).

The escalating energy intensity of data centers poses critical challenges for energy efficiency, energy transition, and sustainable development within contemporary energy policy frameworks. Rapid growth in cloud computing has positioned data centers among the most electricity-intensive facilities, resulting in substantial carbon emissions and environmental degradation, including contributions to global warming and ozone depletion (Bharany et al., 2022; Panwar et al., 2022). Prior studies identify power distribution systems, ICT equipment, and non-ICT components—particularly cooling systems—as the primary drivers of energy consumption in data centers (Manganelli et al., 2021). To address these challenges, a wide range of strategies has been proposed, including advanced cooling techniques, automation, and the deployment of low-power electronics (Manganelli et al., 2021). In addition, energy-efficient methodologies based on machine learning, heuristics, and metaheuristics have demonstrated considerable potential to reduce energy consumption, with reported efficiency gains ranging from 1.6% to 97%, depending on context and implementation (Panwar et al., 2022). Complementary approaches such as virtual machine virtualization, power-aware resource management, and thermal optimization are also critical for mitigating the carbon footprint of cloud data centers (Bharany et al., 2022). Novel power control algorithms, including the Modified Differential Evolution method, seek to balance energy efficiency with server stability, achieving average energy consumption reductions of approximately 13% while lowering cooling-related power demand (Li et al., 2022). Analytical tools such as the Escope simulator further assist operators in understanding and improving energy efficiency across diverse server architectures, thereby supporting more informed strategic decisions regarding server deployment and utilization (Lu et al., 2023).

Against this backdrop, the evolution of green data centers emphasizes not only energy efficiency and the integration of renewable energy but also the enhancement of governance practices through Environmental, Social, and Governance (ESG) frameworks. This shift reflects growing recognition of the need to address the environmental impacts of data centers, which are major energy consumers and CO_2 emitters, through more holistic sustainability approaches. Techniques such as virtualization and thermal management continue to optimize energy use and reduce carbon footprints, with particular emphasis on software-based solutions due to their lower infrastructure requirements and lower risk of failure (Bharany et al., 2022). Broader sustainability strategies further encompass innovative cooling technologies, automation, and low-power electronics, all of which play a crucial role in improving overall energy efficiency (Manganelli et al., 2021). The integration of ESG principles is further reinforced by social innovation, circular-economy practices, and energy transitions, which are essential to achieving long-term sustainability objectives (Popescu et al., 2022). Empirical evidence from China demonstrates that national green data center pilot policies can promote green technological innovation, particularly in cities facing environmental constraints (Liu and Yang, 2023). Moreover, the concept of carbon-responsive computing advocates a systemic approach that combines decentralized renewable energy with computing infrastructures while accounting for governance and social power dynamics (Nafus et al., 2021). Collectively, these studies highlight the multifaceted nature of green data center development, where technological advancement, policy alignment, and governance considerations are increasingly interconnected.

Despite the expanding body of research on green energy, sustainability, and digital infrastructure, the existing literature remains fragmented and predominantly oriented toward technical and environmental dimensions. Economic integration and the strategic implications of sustainability-driven digital technologies are comparatively underexplored. For instance, Cricelli and Strazzullo (2021) emphasize the potential of digitization to enhance sustainable production and innovation, yet note the limited examination of its broader economic integration. Khatami and Goharian (2022) propose a comprehensive framework for power plant sustainability that integrates social and technical criteria using the Relative Aggregate Footprint method, underscoring the importance of multidimensional sustainability assessment. Chopra et al. (2023) further explore the socioeconomic dimensions of digitization, advocating for inclusive economic models and greater consideration of the social consequences of technological advancement. In a similar vein, Androniceanu and Sabie (2022) highlight the strategic role of green energy in sustainable development, aligning energy transitions with global commitments to renewable energy adoption and emissions reduction. Chen et al. (2023) additionally, demonstrate that improvements in environmental performance enabled by digital servitization can translate into enhanced financial outcomes, suggesting an intrinsic link between sustainability and competitiveness. Together, these studies signal increasing awareness of the need to integrate economic and strategic perspectives into sustainability research, while also revealing the absence of a focused analytical framework for data centers.

In parallel, systematic literature reviews and bibliometric analyses have been widely employed to map research developments in green energy, digital sustainability, and energy optimization. Mentel et al. (2023) emphasize the role of technological and process innovations in addressing climate change and energy-efficiency challenges, aligning closely with the objectives of green data centers. Bendig et al. (2023) systematic review of green manufacturing offers a structured framework for examining the drivers and outcomes of green practices, which can be conceptually extended to the data center context. The review of Green AI by Verdecchia et al. (2023) further underscores the importance of monitoring and optimizing energy consumption in data-intensive computing systems, a concern directly relevant to data center operations. Hanafi et al. (2022) bibliometric analysis of energy optimization research illustrates the growing global interest in this domain, with significant contributions from countries such as China and the United States. Bąk and Cheba (2022) statistical analysis of green transformation similarly demonstrates how bibliometric and quantitative methods can be used to identify emerging themes and research gaps in sustainability-related studies. While these reviews provide valuable methodological insights, they generally adopt broad thematic scopes and do not explicitly center on green data centers as a distinct object of strategic and economic analysis.

Addressing this limitation, the present study advances the literature by reframing green data centers from being merely energy-efficient digital infrastructures to strategic assets embedded within organizational ESG strategies, thereby bridging sustainability research with strategic management perspectives. By integrating bibliometric mapping with a strategic asset lens, this research uniquely reveals how green data centers are positioned in the literature not only as environmental solutions but also as potential sources of competitive advantage and governance capability.

Accordingly, this study employs a systematic literature review combined with bibliometric analysis to map the intellectual structure, thematic evolution, and research fronts of green data center research. By synthesizing insights from energy economics, sustainability, and strategic management, the study aims to provide a comprehensive overview of existing scholarship and to identify key research gaps and future directions relevant to policymakers, industry practitioners, and academics concerned with the sustainable development of energy-intensive digital infrastructure.

2. METHODOLOGY

2.1. Research Design and Bibliometric Approach

This study employs a systematic literature review (SLR) combined with bibliometric analysis to map the development, intellectual structure, and research trajectories of studies on green data centers as strategic assets within the contexts of energy efficiency, ESG, and competitive advantage. Bibliometric analysis is particularly suitable for synthesizing large bodies of literature in an objective, transparent, and replicable manner, enabling the identification of dominant themes, knowledge structures, and emerging research fronts that are difficult to capture through conventional narrative reviews (Donthu et al., 2021). In line with established bibliometric practice, this study integrates performance analysis and science mapping to provide a comprehensive overview of the field and to reveal strategically relevant research gaps.

2.2. Data Collection and Inclusion–Exclusion Criteria

Bibliographic data were retrieved from the Scopus database, selected for its extensive coverage and consistent, high-quality metadata suitable for bibliometric studies (Aria and Cuccurullo, 2017). A structured search query was applied to titles, abstracts, and keywords to capture publications related to green data centers, energy efficiency, sustainability, ESG, and competitive advantage. The initial search yielded 3,774 documents. To ensure relevance and analytical rigor, the dataset was subsequently refined by limiting the publication period to 2015–2025, restricting document types to peer-reviewed journal articles, and including only English-language publications. Following this screening process, a final dataset of 1,431 articles was obtained and used for all subsequent analyses.

2.3. Bibliometric Analysis Techniques and Tools

The bibliometric analyses were conducted using the Biblioshiny web-based interface to the Bibliometrix package, implemented in R (Aria and Cuccurullo, 2017). The analysis began with descriptive performance indicators, including annual publication trends, leading journals, prolific authors, and citation patterns. Subsequently, science mapping techniques were applied to uncover the field's conceptual and intellectual structure, including citation analysis, co-citation analysis, bibliographic coupling, co-word analysis, and co-authorship analysis (Donthu et al., 2021; Zupic and Čater, 2015). These techniques enabled the identification of thematic clusters, foundational literature, collaborative networks, and evolving research directions at the intersection of energy economics, ESG, and strategic management.

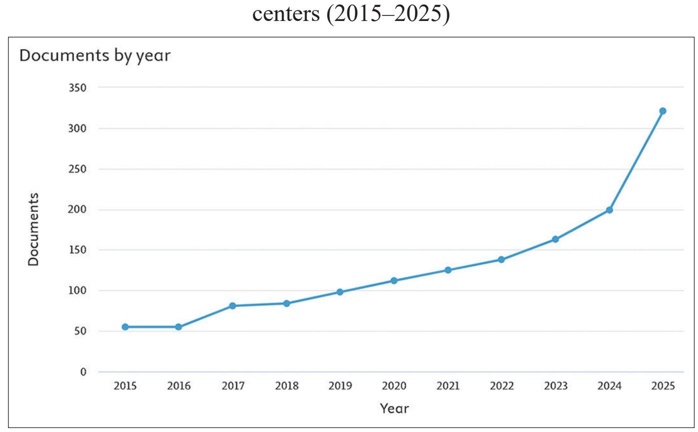
2.4. Visualization and Interpretation Framework

The results of the bibliometric analyses were visualized using network maps, thematic clusters, and temporal trend plots to facilitate interpretation of the field's knowledge structure and dynamics. Visualization served as an analytical tool rather than an end in itself, supporting deeper conceptual interpretation. The findings were interpreted through the lenses of energy economics and strategic management, allowing the study to move beyond descriptive mapping and to assess how green data centers are positioned in the literature not only as environmentally sustainable infrastructure but also as potential strategic assets within ESG-oriented organizational strategies.

3. RESULTS AND DISCUSSION

The descriptive overview of the literature, as presented in Figures 1 and 2, reveals both the temporal expansion and the publication outlets that have shaped research on green data centers. Figure 1 shows a clear and sustained upward trend in annual scientific output from 2015 to 2025, with a particularly sharp acceleration after 2020, indicating a structural shift in scholarly attention toward energy efficiency and sustainability in digital infrastructure. The relatively modest growth observed between 2015 and 2018 suggests that early studies primarily situated data center research within broader technical and computational discourses, rather than explicitly within sustainability or energy economics perspectives. In contrast, the rapid increase in publications in the later period reflects growing academic concern over the energy intensity of data centers, their expanding electricity demand, and their environmental implications within

Figure 1: Annual scientific production on green data centers (2015–2025)



the digital economy. Complementing this temporal pattern, Figure 2 highlights the most relevant publication sources, showing that research output is concentrated in technically and energy-oriented journals such as IEEE Access, Energy, Applied Energy, and Energies. This distribution indicates that the field has been predominantly driven by engineering and energy systems perspectives, with sustainability-oriented outlets also gaining visibility. Taken together, these findings suggest that while the volume of research on green data centers has expanded significantly, the literature remains anchored mainly in technical and energy-efficiency domains, thereby providing a critical empirical context for subsequent analyses of intellectual structure, thematic development, and the strategic positioning of green data centers within the energy economics literature.

The geographic distribution of corresponding authors, as illustrated in Figure 3, reveals a pronounced concentration of research output on green data centers in a limited number of countries, highlighting both centers of knowledge production and existing global imbalances in scholarly contributions. China emerges as the most prolific contributor, followed by India and the United States, indicating that research on green data centers is predominantly driven by countries experiencing rapid digital infrastructure expansion and rising energy demand. The dominance of single-country publications (SCP) across most leading countries suggests that national research agendas and domestic policy priorities play a central role in shaping scholarly output in this field. At the same time, the presence of multiple-country publications (MCP)—particularly among leading contributors such as China, the United States, and several European countries—signals the growing importance of international collaboration in addressing the complex energy and sustainability challenges associated with data centers. Nevertheless, the relatively limited participation of developing regions underscores persistent geographic disparities in research capacity and cross-border collaboration. Taken together, these patterns indicate that while green data center research is gaining global visibility, its knowledge production remains unevenly distributed, with implications for the diffusion of best practices, policy learning, and the global governance of energy-intensive digital infrastructure.

Figure 4 provides an initial overview of the field's intellectual foundations by identifying the most-cited documents in the green data center research corpus. The citation profile is highly

Figure 2: Most relevant publication sources on green data center research (2015–2025)

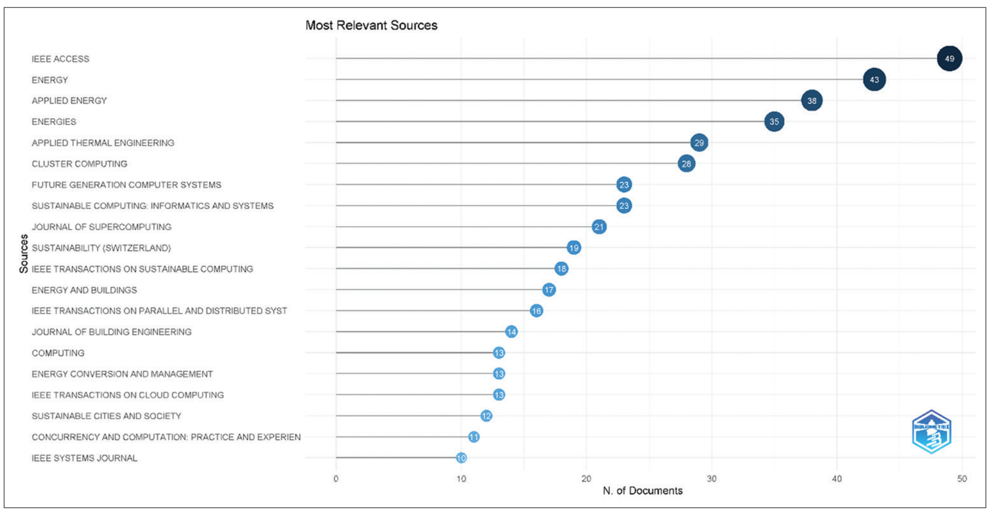
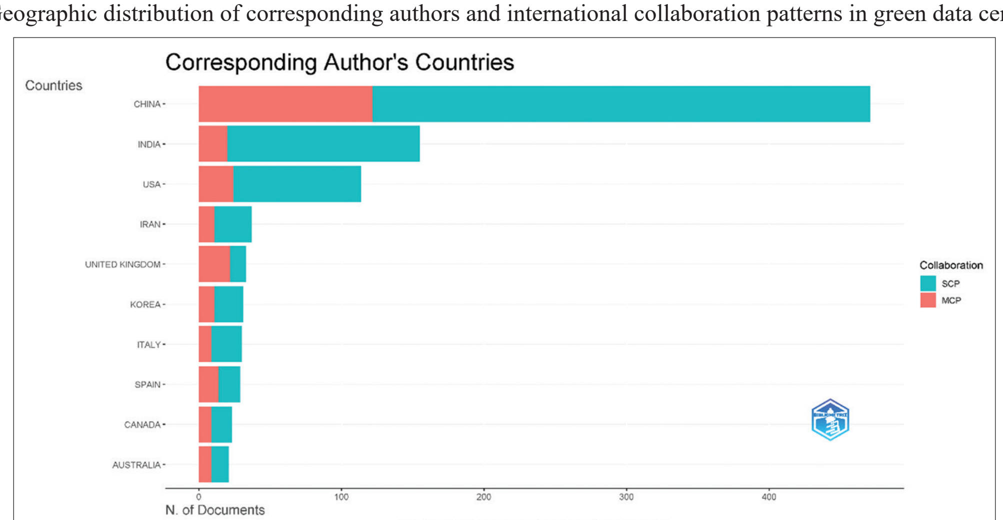


Figure 3: Geographic distribution of corresponding authors and international collaboration patterns in green data center research



concentrated, with a small set of publications accumulating substantially higher global citations than the remainder, indicating that a limited number of foundational contributions have shaped the domain. Overall, the most influential works predominantly reflect technology- and efficiency-oriented trajectories—such as large-scale computing performance, energy-aware system optimization, and sustainability-linked efficiency debates—suggesting that the early and most impactful knowledge base has been anchored in operational and engineering problem frames rather than in strategic management or ESG governance lenses. This pattern is consistent with the interpretation that the field's intellectual roots prioritize measurable efficiency and system performance outcomes as the primary entry points for "greenness."

Beyond individual influential works, Figure 5 maps the co-citation network and clarifies how the knowledge base is structured into distinct yet connected clusters of sources. The network visualization shows a prominent cluster centered on computing and systems outlets (e.g., high-performance and distributed computing venues), reflecting the dominance of research streams in workload management, virtualization, and resource allocation. A second central cluster is anchored in energy and built-environment journals (e.g., Applied Energy, Thermal Engineering, and energy-and-buildings outlets), indicating that thermal management and energy efficiency are tightly coupled to the field's core intellectual development. A third, bridging cluster links sustainable computing and communication-related sources, suggesting interdisciplinary connections between computing optimization and sustainability narratives. The existence of multiple clusters with visible cross-links indicates partial integration across technical and energy-oriented traditions. However, it also implies that knowledge development remains segmented by disciplinary starting points.

Figure 6 supports this interpretation by presenting the co-citation density map, which highlights the areas of most excellent scholarly attention. The densest regions are located around energy-efficiency and computing-system cores, indicating mature and well-institutionalized knowledge bases. In contrast, areas with lower density appear more peripheral and weakly integrated, implying fragmented or emerging substreams that have not yet converged into a stable core. Notably, the density structure provides indirect evidence that strategic and governance-oriented perspectives—particularly those explicitly tied to ESG strategy and competitive advantage—remain outside the highest-density zones, reinforcing the view that the field's mainstream intellectual base is still primarily dominated by technical and energy-performance paradigms.

Figure 4: Most globally cited documents in green data center research (global citations)

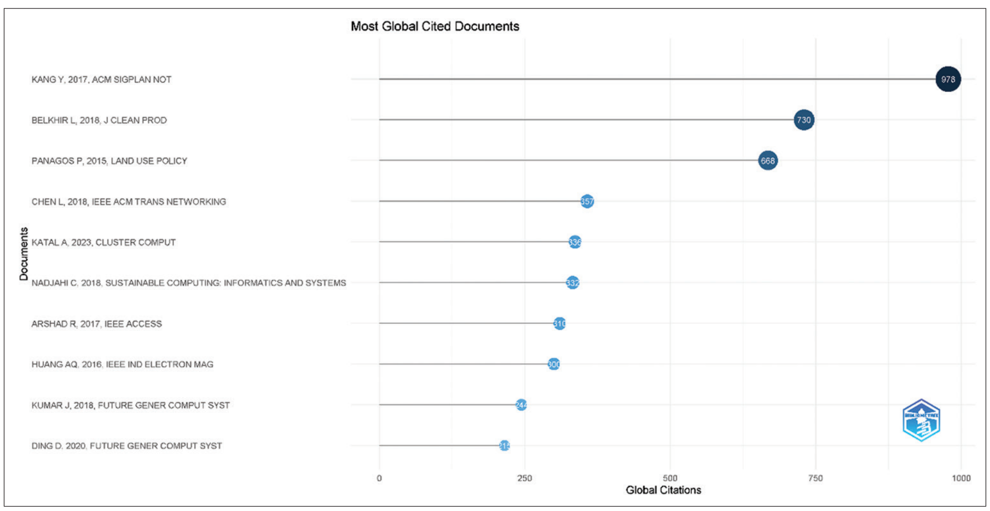
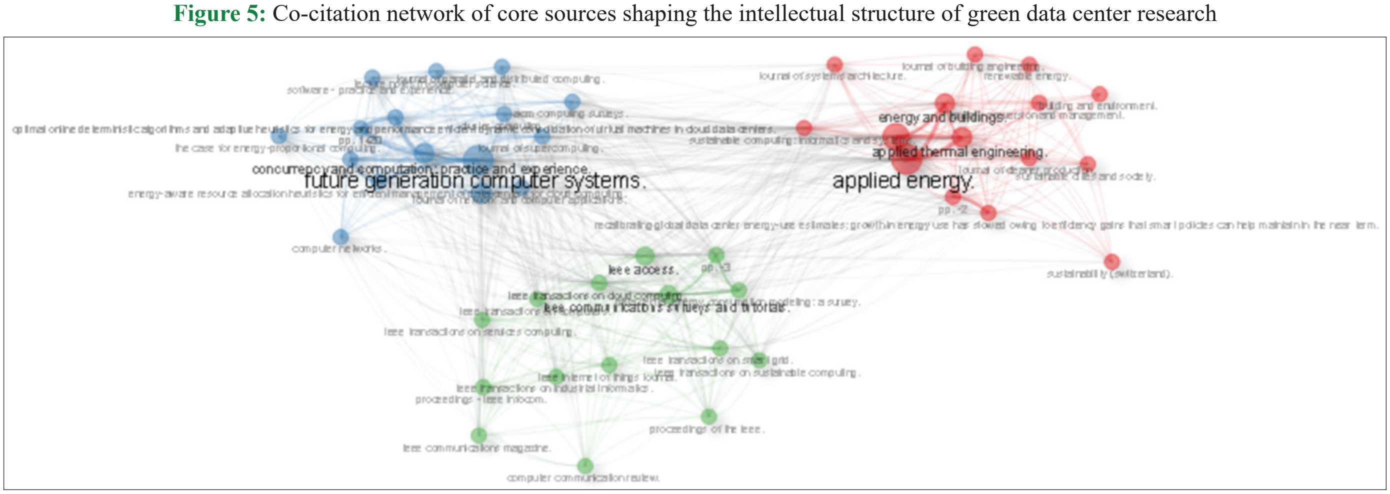


Figure 5: Co-citation network of core sources shaping the intellectual structure of green data center research



Building on the intellectual foundations revealed by the citation and co-citation analyses, the following section examines the conceptual structure of green data center research through co-word and thematic mapping to identify dominant themes, emerging topics, and underexplored conceptual linkages.

Figures 7 and 8 reveal the conceptual backbone of the green data center literature by mapping co-occurrence relationships among the most salient keywords. The co-word network indicates that the field is organized around a small set of highly central concepts—most notably "energy efficiency," "green computing," and "energy utilization"—which function as the primary hubs connecting technical, operational, and sustainability-related discussions. The surrounding keyword neighborhoods further suggest two broad yet interlinked emphases: one oriented toward data-center operations and sustainability outcomes (e.g., carbon footprint, renewable energy, cooling systems, energy management), and another centered on computing and resource orchestration (e.g., cloud computing, virtual machine, scheduling, resource allocation, quality of service). The density visualization (Figure 8) corroborates this structure by showing the highest concentration of conceptual activity around these core hubs, implying that the literature's dominant conceptualization of "green" remains firmly anchored in measurable efficiency and utilization logics, with adjacent topics extending into optimization, energy consumption, and infrastructure-level management.

Figure 9 further refines this interpretation by classifying themes by centrality (relevance) and density (development). The thematic map places energy efficiency/green computing/energy utilization in the motor theme quadrant, indicating that these topics are both well-developed and highly central to the field's conceptual system. In contrast, "datacenter/data center/data centers" appears to be positioned in the lower-density region, suggesting that—despite being an intuitive label for the domain—the concept functions more as a broad anchor than as a tightly developed thematic core within the keyword structure. Additional terms such as optimization, digital storage, and electric power utilization appear

Figure 6: Co-citation density map highlighting highly concentrated knowledge bases in green data center research

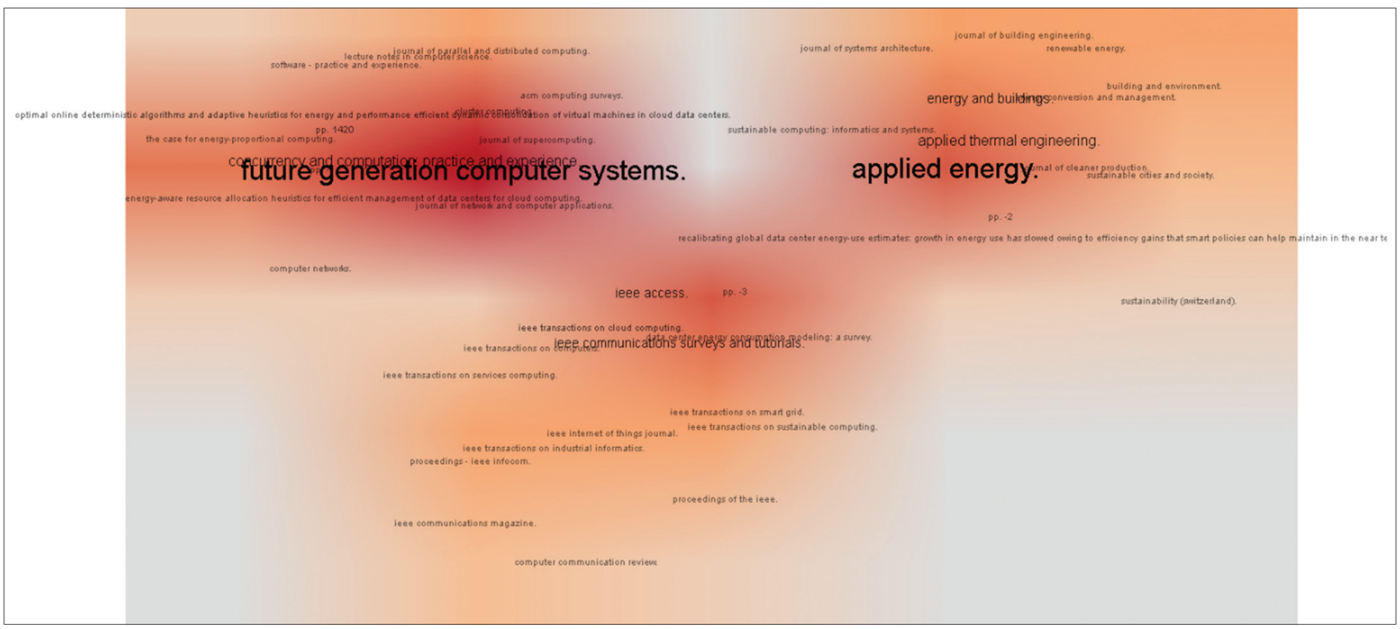


Figure 7: Keyword co-occurrence network of green data center research (author keywords)

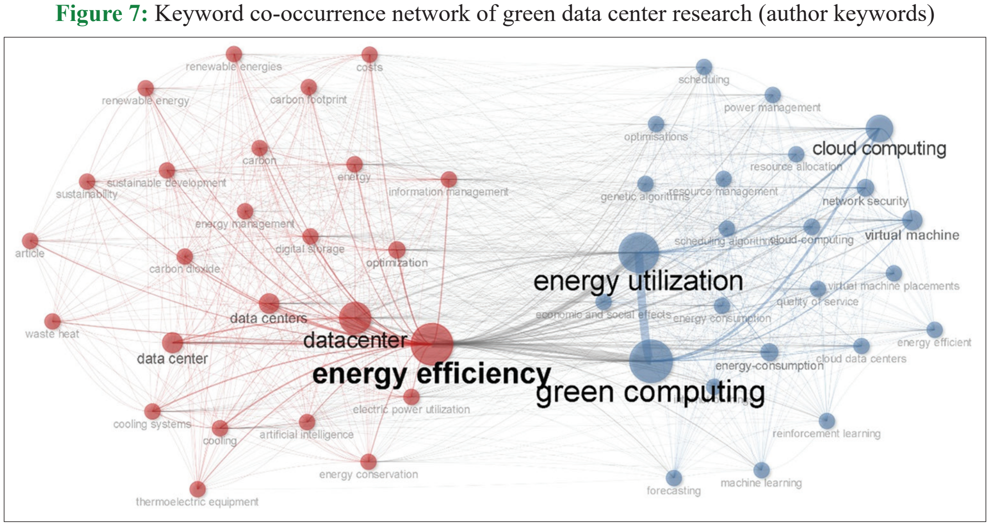


Figure 8: Keyword co-occurrence density map highlighting the most frequent and strongly connected concepts

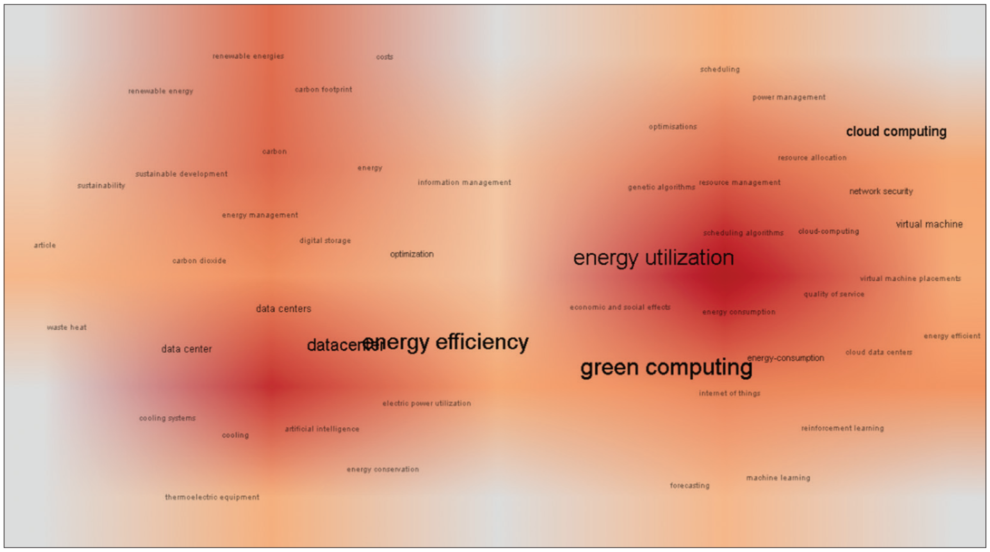
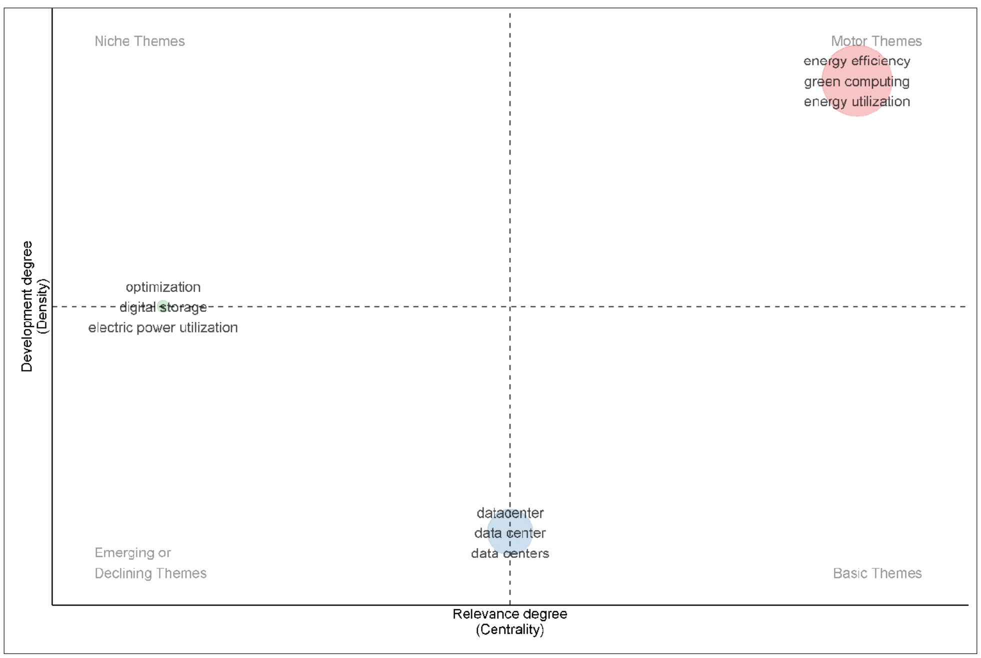


Figure 9: Thematic map of the conceptual structure in green data center research (centrality–density)



outside the motor theme, suggesting either specialized substreams or themes that have not yet been consolidated within the literature's main conceptual engine. Taken together, the co-word and thematic mapping results indicate that the conceptual structure of green data center research is dominated by efficiency-oriented constructs and computing–energy integration. At the same time, broader strategic framings remain weakly articulated at the level of keyword-driven thematic organization.

Building on this conceptual snapshot, the following section traces how these themes have evolved, identifying shifting research trajectories and emerging directions in green data center scholarship.

Figure 10 depicts the thematic evolution of the green data center literature by tracing how dominant keyword themes transition from 2015–2022 to 2023–2025, thereby revealing the field's temporal research trajectories. The visualization indicates strong thematic continuity, in which early emphases on energy efficiency, optimization, digital storage, and green computing persist and reconfigure into a more consolidated set of focal themes in the later period, namely green computing, optimization, and data centers. This pattern suggests that foundational, efficiency-oriented research streams did not disappear but instead increasingly converged toward a clearer domain framing around "datacenter" as an explicit anchor, while retaining optimization and green computing as stable conceptual engines. Notably, the prominence of optimization and green computing across both periods reflects a sustained orientation toward performance- and efficiency-driven solutions, whereas the emergence of datacenter as a salient endpoint theme in 2023–2025 signals a tightening of conceptual boundaries from broader enabling technologies (e.g., storage) toward a more direct articulation of the infrastructure object itself. Taken together, the thematic evolution highlights a trajectory of consolidation rather than disruption, indicating that the literature has progressively organized its research agenda around operational efficiency and computing-centric sustainability logics, which provides an empirical basis for assessing how (and to what extent) broader strategic framings may—or may not—become integrated in subsequent research fronts.

Building on these temporal trajectories, the following section applies bibliographic coupling to identify the most recent research fronts and how contemporary studies cluster around emerging directions.

Figure 11 presents the bibliographic coupling network at the document level, illustrating the current research fronts in the green data center literature. The network reveals a clearly differentiated three-cluster structure, indicating that recent studies tend to converge around distinct but interconnected research streams rather than a single unified paradigm.

The first cluster (red) represents a dominant stream focusing on computational efficiency, cloud infrastructure, and performance optimization, as evidenced by highly coupled works published in journals such as the Journal of Supercomputing, the Journal of Systems and Software, and Parallel and Distributed Computing. Seminal contributions within this cluster (e.g., Tarafdar et al., Zhou et al., Zhang et al.) emphasize workload scheduling, virtualization, and energy-aware resource management as technical solutions to reduce data center energy consumption. Despite frequent references to sustainability outcomes, this cluster remains primarily technology-driven, with limited engagement with broader perspectives in energy economics or organizational strategy.

The second cluster (blue) captures a research front centered on energy systems integration, renewable energy utilization, and sustainability assessment, with strong representation from journals

Figure 10: Thematic evolution of green data center research across two periods (2015–2022 vs. 2023–2025)

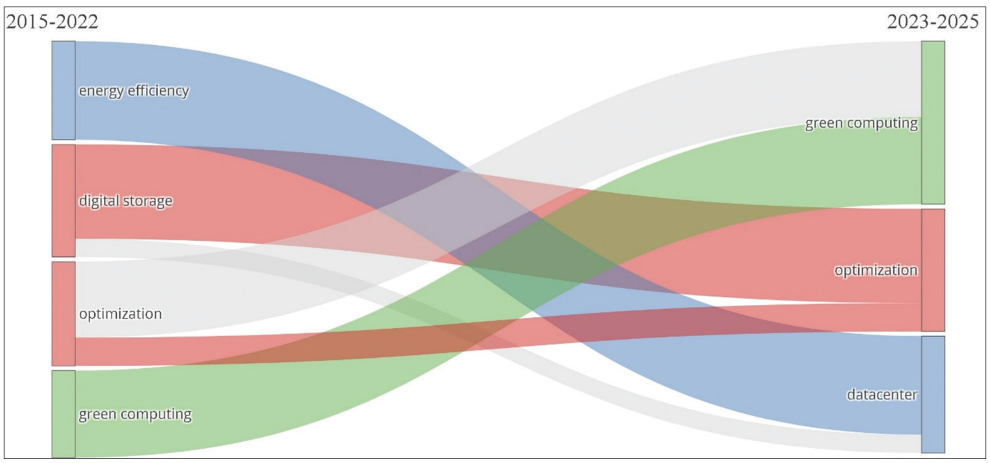
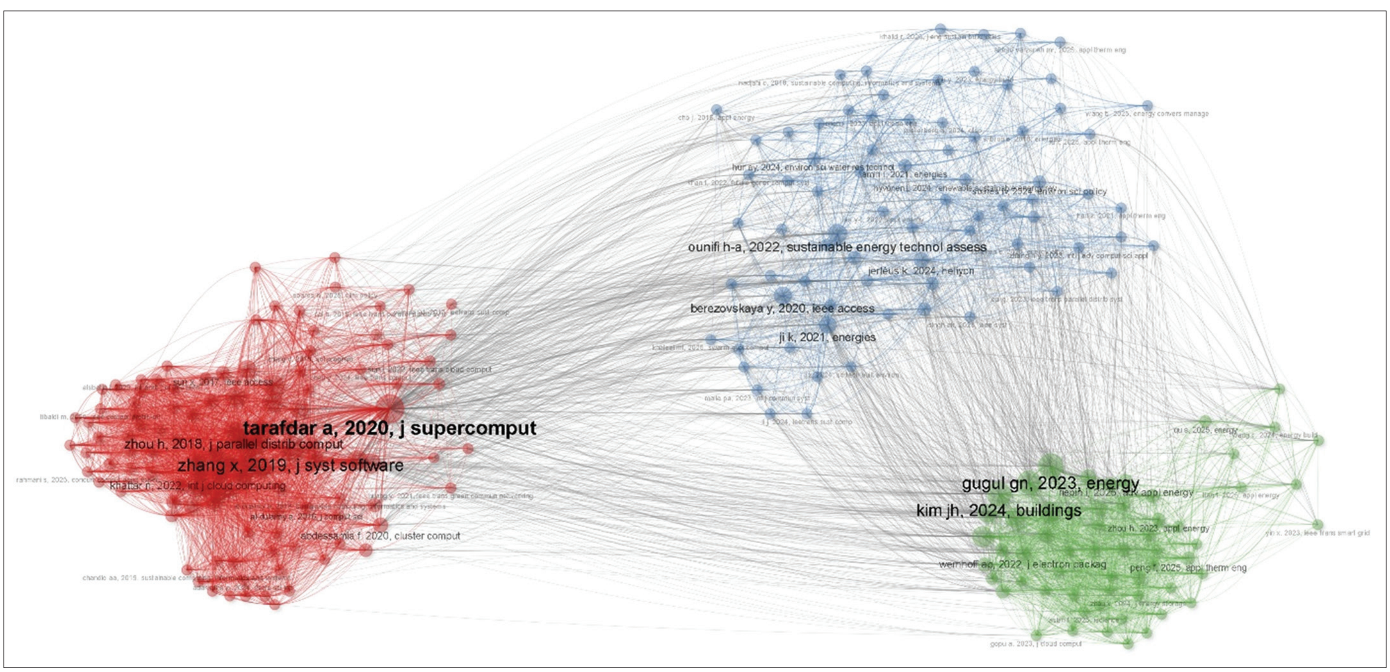


Figure 11: Research fronts of green data center studies based on bibliographic coupling analysis



such as Sustainable Energy Technologies and Assessments, Energies, and IEEE Access. Highly coupled studies in this cluster examine power grid interactions, energy storage, carbon mitigation, and system-level efficiency modeling. Compared with the red cluster, this stream demonstrates a clear shift from micro-level computing-optimization toward macro-level energy-system considerations, reflecting a growing alignment with energy policy and decarbonization agendas. However, strategic interpretations of data centers as organizational or economic assets remain largely implicit rather than explicitly theorized.

The third cluster (green) reflects an emerging research front linking green data centers to buildings, infrastructure efficiency, and applied energy performance, as evidenced by influential works published in Energy, Buildings, and Applied Energy. Studies within this cluster increasingly frame data centers as components of the built environment, integrating thermal management, architectural design, and lifecycle energy efficiency. Although smaller, this cluster exhibits strong internal coupling, suggesting a rapidly consolidating research trajectory that bridges engineering design and applied energy economics.

Overall, the bibliographic coupling structure indicates that current green data center research is fragmented across technical, energy-system, and infrastructure-oriented fronts, with only partial conceptual integration among them. While the clusters are interconnected through shared references on energy efficiency and sustainability, explicit linkages to ESG frameworks, strategic management, and competitive advantage remain weak and underdeveloped, reinforcing the notion that the research front has not yet fully matured into a cohesive strategic discourse within energy economics.

From a strategic perspective, the bibliographic coupling results provide critical evidence of a conceptual gap in the current research front. Although green data centers are increasingly examined through the lenses of energy efficiency, renewable integration, and infrastructure optimization, they are still predominantly treated as technical or operational systems rather than strategic organizational assets. This fragmented research landscape suggests that sustainability considerations have advanced faster than their integration into ESG-oriented governance frameworks and competitive strategy models.

The novelty of this study lies in positioning green data centers as strategic assets at the intersection of energy economics, ESG, and competitive advantage, rather than as isolated engineering solutions. By synthesizing fragmented research fronts revealed through bibliographic coupling, this study contributes an integrative perspective that highlights the need to reconceptualize data centers as value-creating infrastructures capable of influencing firm-level competitiveness, regulatory positioning, and long-term sustainability performance. For policymakers and industry stakeholders, these findings imply that future research and policy design should move beyond efficiency metrics toward strategic governance, investment prioritization, and ESG alignment, thereby unlocking the full economic and strategic potential of green data centers within the digital energy transition.

4. CONCLUSION

This study presents a systematic bibliometric synthesis of the green data center literature, mapping its publication dynamics, intellectual foundations, conceptual structure, and thematic evolution from 2015 to 2025. The results demonstrate a marked expansion of scholarly attention, particularly after 2020, reflecting the growing relevance of data centers as energy-intensive infrastructures within the digital economy. Citation and co-citation analyses reveal that the field has been predominantly shaped by highly influential studies rooted in computing systems optimization and energy efficiency. In contrast, conceptual and thematic analyses indicate that energy efficiency and green computing serve as the core motor themes guiding research development. The thematic evolution further indicates a trajectory of consolidation, whereby early efficiency-oriented themes converge toward a more explicit focus on data center infrastructures, without a parallel integration of strategic management or ESG-oriented perspectives. Taken together, these findings suggest that, despite rapid growth and increasing policy relevance, green data centers continue to be conceptualized primarily as technical and operational solutions rather than as strategic assets embedded within broader organizational ESG and competitive advantage frameworks. By clarifying these structural patterns, this study contributes to the energy economics and sustainability literature by providing an integrated overview of the field and identifying critical directions for advancing more strategic interpretations of green digital infrastructure.

Notwithstanding its contributions, this study is subject to several limitations that open avenues for future research. First, the analysis relies exclusively on Scopus-indexed journal articles, which, while ensuring data quality and consistency, may omit relevant contributions from other databases or non-journal sources. Second, bibliometric methods focus on publication and citation relationships, capturing structural and thematic patterns but not evaluating the empirical depth or contextual specificity of individual studies. Third, the co-word analysis depends on author-provided keywords, which may vary in consistency across publications and over time. Future research could address these limitations by incorporating multiple databases, combining bibliometric mapping with qualitative systematic reviews or content analysis, and examining empirical case studies that link green data centers to firm-level performance, governance mechanisms, or policy outcomes. In particular, further studies are encouraged to explore how green data centers can be operationalized as strategic assets within ESG frameworks, thereby extending the predominantly efficiency-driven discourse toward more integrated economic, organizational, and institutional perspectives.

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